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Impact of mechanization on technical efficiency: A case study of rice farmers in Iran

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Abstract

The main objective of this study was to evaluate the impact of mechanization inputs and cultivation systems on the productivity and technical efficiency (TE) of rice production in the Khuzestan province in the southwestern part of Iran. A stochastic frontier analysis was used to measure the TE and three methods in each cultivation stage were assessed. The data analyzed in this study were collected during a survey that covered the crop year of 2009 in two climatic regions. There was a great variation in the levels of efficiency, which ranged from 0.15 to 0.99 with a mean of 0.67. The mechanization index ranged from 0.06 to 0.52, showing a high variation in the application of farm machinery for rice production. The correlation between the mechanization index and TE strongly demonstrated the impact of mechanization on the efficiency of rice producers.

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Keywords: rice production systems, technical efficiency, cultivation methods, mechanization

1. Introduction

Rice is one of the most important cereal crops grown globally. Rice is important as a staple human food source in many areas of Iran, where the per capita consumption of rice is approximately 100 grams per day. In

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2008, which was a drought year, statistics show that Iran had 527,000 hectares of paddy cultivation. The Khuzestan province is normally known as the fifth largest rice producer, with 15,000 hectares devoted to rice production; nonetheless, due to low productivity, the paddy production of Khuzestan was announced to be sixth highest in Iran in 2008 (MJA, 2008). In a normal year, rice-cultivated areas may reach 59,000 hectares (MJA, 2006); however, the nearly 1400-kg/ha difference among the regions of Khuzestan shows there are other variables that affect productivity (AOKP, 2007).

The government's efforts toward self-sufficiency in rice production have not yielded the required results. The government's goal of achieving self-sufficiency in rice production depends on the level of the farmers' productivity, which can be determined by their rates of adoption of improved technologies and the efficiency of the resources used. However, the low rates of adoption of rice technologies by farmers as a result of resource poverty, among other reasons, makes the improvement of efficiency an important and significant factor in increasing productivity (Idiong, 2007; Shehu and Meshelia, 2007). Moreover, increasing land and labor productivity represent mechanization requirements for developing countries like Iran. Mechanization technology is location-specific and dynamic; therefore, the quality of the inputs of mechanization and, consequently, the land and labor productivity in both situations, may differ considerably (Sing, 2006; Tabatabaefar and Omid, 2005). Mechanization planning requires the quantitative assessment of a mechanization index and its impact on agricultural production (yield) and economic factors (Sing, 2006; Rasooli Sharabiani and Ranjbar, 2008).

In this paper, we examined the levels and determinants of rice producers' technical efficiency (TE), focusing on the impact of mechanization with the aim of investigating the extent to which rice production can be improved under existing technologies and identifying agricultural systems that have a positive effect on production.

Experiences with quantifying the impact of mechanization on agricultural production efficiency in Iran are scarce. The available studies include Shamsabadi and Moradi (2001), who used data from a survey conducted in three regions in the Fars province to examine the impact of transplanters on the technical efficiency of rice producers. The results indicate that the application of a transplanter can have different effects on the technical efficiency of rice producers inasmuch as it has a negative effect on the TE of the Mamassani region and has an insignificant effect on other regions. They estimated TEs of 87%, 85% and 83% for the Shiraz, Mamassani and Marvdasht regions, respectively. Karami and Zibai (2001) estimated the technical efficiency of three major rice producers in Iran to be 80.3%, 83.9% and 68.8% for the Fars, Gilan and Mazandaran provinces, respectively.

Bakhshoodeh and Thomson (2001) measured the TE of wheat producers in Kerman province, Iran, using the Cobb–Douglas frontier function. They demonstrated that the level of inefficiency was a function of farm size. In addition, wheat producers may be able to adopt their production process more easily and quickly by implementing new techniques, i.e., by more efficient combinations of inputs, than by adopting new technology.

1.1. Current status of rice production systems in Khuzestan province

Several techniques are being applied to produce rice in the Khuzestan province, and their combinations can have different impacts on crop yield. These methods are described below.

Tillage methods include: (a) dry plowing plus harrowing, which is known as conventional tillage. This method usually involves moldboard plowing and double disk. (b) Harrowing is another tillage method, which is defined as reduced tillage. This method includes engaging the double disk, and it consumes less water than conventional tillage. (c) Dry plowing plus puddling is applied in mountainous regions where plots are permanent and is applied by either a chisel or a puddler. (d) Ripping is applied in weak drainage lands, where, due to water logging in the rainy season, farmers have been forced to cultivate single crops in the summer, such as rice. Nevertheless, the construction of drainage systems has recently begun. This method is applied

using a ripper bulldozer, as in the Ahudasht region of Susa. In this study, methods (a) and (d) were considered to be intensive tillage methods.

Three methods have been applied for planting rice in the Khuzestan province. One method involves transplanting in which rice is grown by transplanting one-month-old seedlings into puddled and continuously flooded land. The seedlings are transplanted without a definite distance or space between the plants. This technique imposes a high labor demand for uprooting nursery seedlings and transplanting seedlings into fields. Another method is the direct seeding of rice, which refers to the process of establishing a rice crop from seeds sown in the field rather than by transplanting seedlings from the nursery (Farooq et al., 2011). There are two methods for directly seeding rice: direct seeding on a wet field, known as wet seeding, where seeds are broadcasted in mud and direct seeding in dry soil, known as dry seeding, where seeds are sown using a drill machine. This method is one of the aerobic rice systems that are being used more extensively to reduce water consumption, labor and capital input (Sing et al., 2006).

Weed control, which is one of the main problems for rice producers in Khuzestan province, is often done by hand; however, dry seeding farmers also use hose-end sprayers for weed control.

Several methods and techniques have been applied to harvesting paddies. Some of these methods greatly depend on variety, soil moisture and topography. Harvest methods that are used by rice producers include the following: (x) multi-stage harvesting, which is considered to be a traditional method in which laborers not only cut paddy crops, but also clean them, and threshing is done by tractor wheels. (y) Two-stage harvesting is considered to be semi-mechanized. In this method, a machine is utilized as a thresher in three practices. The laborers reap the crops, and threshing is done either in the field or at the harvesting floor by means of a drawn paddy thresher, a cereal combine harvester without a reel, or a cereal combine harvester with a special header called a pot header. (z) Direct harvesting is done either by a paddy harvester or a cereal combine harvester.

2. Methods

2.1. Technical Efficiency

The stochastic frontier production approach, which was developed by Aigner et al. (1977), was utilized in this study. We extended the framework to include variables representing rice production systems related to agricultural machinery in addition to physical inputs to explain productivity performance, as described by Rahman and Hasan (2008). The stochastic frontier production is expressed as the following equation:

$$Y_i = f(X_i, R_i) - u_i + v_i \quad (1)$$

where Y_i is the output, X_i is the vector of the physical inputs, R_i is the vector of the rice production systems, u_i is a non-negative random variable associated with a farmer's specific factors that contribute to the farmer's inability to attain maximum efficiency and v_i is a random error with a zero mean, which is associated with random factors not under the control of the farmer. The two components of the composed error terms v and μ are assumed to be independent, where v is the two-sided, normally distributed random error, $v \sim N(0, \sigma_v^2)$, and μ is the one-sided inefficiency component with a half-normal distribution, $\mu \sim [N(0, \sigma_u^2)]$. Jondrow et al. (1982) proposed that farm-level technical efficiencies could be estimated by the conditional expectation of $\exp(-u_i)$. The maximum likelihood estimation of yield estimators, where $\gamma = \sigma_u^2 / \sigma^2$, $\sigma^2 = \sigma_u^2 + \sigma_v^2$, and γ explains the total variation of the output from the frontier that can be attributed to technical inefficiency and lies between zero and one.

2.2. The empirical model

The general form of the Cobb–Douglas stochastic frontier production function was used. The results of the

likelihood ratio-type test, used to test Cobb–Douglas against the translog, showed that Cobb–Douglas was an appropriate model for our data. The Cobb–Douglas specification is widely used in studies (e.g., Rezitis et al., 2002; Rahman and Hasan, 2008). To determine the effects of rice production systems, we estimated the frontier production ‘with’ and ‘without’ dummy variables. Hence, Eq. (1) is written as:

$$\ln Y_i = \alpha_0 + \sum_{j=1}^8 \alpha_j \ln X_{ij} + \sum_{j=1}^7 \beta_j R_{ij} + \nu_i - u_i \quad (2)$$

where Y_i is the paddy output, X_{ij} is the j th input for the i th farmer, R_{ij} are the dummy variables, u_i is the one-sided half-normal error, \ln is the natural logarithm, and α_0 , α_j and β_j are the parameters to be estimated. The Wald test was used to specify the inefficiency effects of the model (including the tillage, sowing and harvest methods).

The parameters of the stochastic frontier were estimated as described by Battese and Coelli (1995). The Frontier 4.1 software package developed by Coelli (1996) was used for this purpose.

2.3. Sampling and data collection

The research survey was undertaken in the Khuzestan province in southwestern Iran. The data used in this study were collected during a survey covering the crop year of 2009 in two climatic regions: (I) mountainous northeastern Khuzestan and (II) the plains (the rest of Khuzestan). Based on the statistics of high rice production districts (Anonymous, 2007), the Baghmalek district from region (I) and the Ahvaz, Shushtar, Susa, Ramhormoz and Dashte-Azadegan districts from region (II) were chosen. Moreover, to reflect the diversity of the rice production systems, the Izeh district was added to region (I) and the Dezful district was added to region (II). Due to the complete colinearity of the climatic region variables with the tillage methods, the former were omitted; therefore, the tillage methods simultaneously reflect the climatic regional effects. A two-stage cluster sampling of 295 households from these two regions was surveyed. The design and data collection were performed under the supervision of one of the authors. Information from these farm households was collected through repeated visits using a questionnaire. The data covered information on farm and non-farm activities as well as demographic and location characteristics. The information collected on farm activities included fertilizer application and prices, human labor, farm size, crop output and prices, wages, capital assets, and livestock production.

Unlike other studies, we separated the machinery practices and the labor applied into three stages: tillage, planting (and maintenance), and harvest. Furthermore, an investigation of the impact of mechanization on productivity and efficiency requires precise data. Many studies have used man-days or person-days to measure labor (Idiong, 2007; Shehu and Meshelia, 2007; Bozoglu and Ceyhan, 2007; Rahman and Hasan, 2008), but the work of the laborers ranged from 6 to 10 hours per day; moreover, due to differences between women and men, the labor inputs were measured based on the energy equivalent (Table 1). Many studies have used hours to measure farm machinery usage (Rahman and Hasan, 2008; Tan et al., 2010); however, in this study, the machinery inputs were measured by machine energy used based on an energy equivalent (Table 1) because we cannot add operations with different capacities based on the hours performed. For example, it is clear that adding cereal combine harvest hours with spaying hours results in an error. Following Mikkola and Ahokas (2010), Eq. (3) was used to calculate the energy used by farm machinery:

$$E_{ha} = \frac{E \cdot M}{T \cdot C} \quad (3)$$

where E_{ha} is the energy for farm machinery in the lifetime allocated to one hectare, MJ kg⁻¹; M is the mass of the machinery, kg; T is the lifetime, h; and C is the field capacity, ha h⁻¹.

Table 1: Energy equivalents of inputs (Nassiri and Singh, 2009)

Particulars	Unit	Equivalent energy, MJ
Human labor-adult man	Man-h	1.96
Human labor-adult woman	Woman-h	1.57
Bullock (medium)	-do-	10.1
Farm machinery: E in Eq. (3)	kg	62.7

A mechanization index based on the matrix of the use of animate and mechanical energy inputs is given by incorporating cost factors (Singh, 2006) and is changed into Eq. (4).

$$I_{Mij} = \frac{C_{Mij}}{C_{Hij} + C_{Aij} + C_{Mij}} \quad (4)$$

where I_{Mij} is the mechanization index of the i th cultivation stage by the j th farmer, C_{Mij} is the cost of the machinery in the i th cultivation stage by the j th farmer, C_{Hij} is the cost of human labor in the i th cultivation stage by the j th farmer and C_{Aij} is the cost of animals in the i th cultivation stage by the j th farmer. This index was used for the quantitative estimation of mechanization and its correlation with TE. The remainder of the statistical analyses were done using the statistical software SPSS (SPSS Inc, 2002).

3. Results and Discussion

Table 2 presents the descriptive statistics for the variables used in the analyses. The corresponding paddy rice production varied from approximately 400 kg to more than 8,000 kg. From the mechanization viewpoint, the critical stages in rice production were the planting and maintenance stages. We can see that most of the labor is invested in the planting stage, with more than 60% of the total labor invested in this stage; in contrast, the machinery use in this stage is only approximately 2%. Transplanting and wet seeding were similar through time, and there were no extended new mechanization technologies, such as a drum seeder for the wet seeding method or a rice transplanter, in the Khuzestan province. Machinery usage in the harvest stage was more than 60% of the total machine energy. These results show that, due to on-time hire payment, a greater investment was made in the harvest stage.

3.1. Results of frontier production function

We analyzed the sign of the third moment and the skewness of the ordinary least squares (OLS) residuals of the data to justify the use of the stochastic frontier framework and, hence, the MLE procedure, which is presented in Table 3.

The estimated parameter γ was close to 1 (0.999), suggesting that the variation in production was mainly caused by a variation in efficiency; σ_u^2 was strongly biased toward σ_v^2 (0.302 over 0.001), and the generalized likelihood ratio statistic value confirmed this.

Table 2: Definition, measurement and summary statistics of variables

Variables	Measurement	Mean	Standard deviation	Minimum	Maximum
Inputs and output					
Paddy rice	kg	3343.05	1343.52	400.00	8050.00
Fertilizer	kg	317.81	156.41	0.00	676.47
Pesticide and herbicide	lit	1.53	1.90	0.00	11.67
Labor					
Tillage (includes land preparation)	MJ	206.94	105.56	47.04	740.88
Sowing (includes maintenance)	MJ	827.00	583.86	111.72	2698.84
Harvest	MJ	283.30	194.46	11.76	740.88
Machinery					
Tillage (includes land preparation)	MJ	291.95	191.60	88.55	786.00
Sowing (includes maintenance)	MJ	16.44	40.53	0.00	157.10
Harvest	MJ	554.55	231.78	39.30	876.00
Rice production systems					
High-yield cultivar	Dummy (1= yes, 0= low-yield cultivar	0.15	0.36	0.00	1.00
Dry seeding	Dummy (1= for either dry seeding or wet seeding, 0= transplanting)	0.10	0.30	0.00	1.00
Wet seeding		0.40	0.49	0.00	1.00
Two-stage harvesting	Dummy (1= for either double-staged or direct, 0= multi-stage harvesting)	0.67	0.47	0.00	1.00
Direct harvesting		0.23	0.42	0.00	1.00
Reduced tillage	Dummy (1= for either reduced tillage or puddling, 0= intensive tillage	0.23	0.42	0.00	1.00
Puddling		0.20	0.40	0.00	1.00
Total number of observations		295			

Table 3: Maximum likelihood estimates of frontier production

Variables	Parameters	With system variables	
		coefficient	t-ratio
Constant	α_0	7.261	5.52***
ln Fertilizer	α_1	-0.007	-0.57
ln Chemical	α_2	0.034	1.60
ln Labor- tillage	α_3	0.095	1.12
ln Labor- sowing	α_4	-0.008	-0.11
ln Labor- harvest	α_5	0.176	1.51
ln Machinery- tillage	α_6	-0.231	-2.72***
ln Machinery- sowing	α_7	0.011	0.96
ln Machinery- harvest	α_8	0.329	1.77*
High-yield cultivar	β_1	0.233	3.35***
Dry seeding	β_2	-0.420	-2.37**
Wet seeding	β_3	-0.206	-1.63
Two-stage harvesting	β_4	-1.008	-1.83*
Direct harvesting	β_5	-0.248	-0.40
Reduced tillage	β_6	0.024	0.27
Puddling	β_7	0.324	2.29**
Variance parameters			
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	σ^2	0.302	6.33***
$\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$	γ	0.999	34399977
σ_u^2		0.302	
σ_v^2		0.001	
Log likelihood		17.47	

*** Significant at (p≤0.01), ** significant at (p≤0.05), * significant at (p≤0.10)

maximum likelihood estimates, the coefficient of machinery in the tillage stage was significant, which implies that a 100% increase in machinery input on the farm results in a 23% decrease in paddy output, demonstrating that tillage in rice farms was done excessively. In this regard, reduced tillage was insignificant; thus, the intensive method (dummy=0) should be replaced by reduced tillage. Table 4 reveals the mechanization index in the tillage methods. The mechanization index of the intensive and reduced tillage was calculated to be 0.33 and 0.27, respectively. As a result of this change, 6% of the operational costs in the tillage stage will be saved. Moreover, reduced tillage through the use of a conservational tillage system results in cost savings for labor, fuel and time (Ozpinar, 2006).

Because of the permanent plots when the puddling method was applied, the mechanization index had the highest value among the other methods (0.49; see Table 4) and was significant (Table 3). Although puddling is a capital- and energy-intensive process and requires a large volume of water, it increased the grain yield of rice from 0.7 to 1 t ha⁻¹ (IRRI, 1985). Puddling also had a number of advantages, including weed control and reduced percolation-based loss of water and nutrients (Sing, 2001). The puddling method also showed the mountain region variable, which was omitted due to collinearity.

Furthermore, high-yield cultivars were strongly significant. The maximum yields obtained from low-yield and high-yield cultivars were 5500 kg/ha and 8050 kg/ha, respectively. The high-yield cultivar is used exclusively by wet seed farmers. Due to the higher price of low-yield cultivars (approximately twice as much as the high-yield cultivar), many farmers tend to cultivate low-yield cultivars; however, the cultivation of high-yield cultivars facilitates harvest in the direct method.

The coefficient of machinery at the harvest stage is significant (Table 3); moreover, the two-stage harvesting method showed a significant and negative effect on rice production. This result implies that two-stage harvesting has a negative effect on output, as compared with multi-stage harvesting. The output of multi-stage harvesting was not different from the direct method. It appears that the dramatic change in rice harvesting technology not only reflects the maximization of the farmer's profit, but might also be a product of other variables. Kikuchi and Hayami (1980) stated that the process of change in rice-harvesting systems in the Philippines from multi-stage harvesting to two-stage harvesting systems illustrated the complex interactions between economic and social forces, resulting in specific technology choices and labor contracts. It is important to recognize that a certain contract is specified for a certain technology. Although contract type was not considered in the present study, the multi-stage harvesting method was only used when migrant workers were working in harvest-sharing contracts; not only do they work hard with minimum crop waste, but they also try to finish the contract to obtain a new one. Table 4 shows the high values of the mechanization index at the harvest stage in the direct, multi- and two-stage harvesting methods, with values of 0.88, 0.52 and 0.34, respectively. The high value of multi-stage harvesting was due to the high harvesting share value of the tractors for crop transport from the field to the harvesting floor in addition to the thresh paddy crop (15% of the harvested grain).

Table 4: Mechanization index of application of methods at different cultivation stages

Cultivation methods		Cultivation stages		
		Tillage	Sowing	Harvest
Tillage	Intensive	0.33 ^a	—	—
	Reduced	0.27 ^a	—	—
	Puddling	0.49 ^b	—	—
Sowing	Transplanting	—	0.00 ^a	—
	Dry seeding	—	0.07 ^b	—
	Wet seeding	—	0.00 ^a	—
Harvest	Multi-stage	—	—	0.52 ^b
	Two-stage	—	—	0.34 ^a
	Direct	—	—	0.88 ^c

Different letters in each column show significant difference at ($P \leq 0.05$)

planting stage, the dry seeding method was negatively significant. This result is supported by the insignificant machinery input in the planting stage because machinery was only used in the dry seeding method. For instance, a drill seeder was applied to direct sowing, and a hose-end sprayer was used to spray herbicide. The main reason for this negative effect was probably insufficient weed control by the farmers. High weed infestation is a major constraint for the broader adoption of the dry seeding method. The loss of the rice yield due to weed competition has been shown to range from 38% to 92% (Singh et al., 2008). The labor requirement for weeding is a major impediment to the adoption of dry seeded aerobic rice, and to increase the productivity of aerobic rice, herbicides have been considered to be an alternative or a supplement to hand weeding. However, the appropriate application time and quantity of herbicides are not usually followed. Transplanted seedlings have a competitive advantage over newly emerged weeds compared with emerging dry seeding method seedlings. In addition, early weeds in the transplanting method were controlled by flooding in contrast to the dry seeding method (Rao et al., 2007). Our results are supported by research that has revealed that the yields of the transplanting and wet seeding methods are comparable and that dry seeded rice yielded less than transplanted and wet seeded rice. The low yield of dry seeded rice made it less attractive to most farmers in many gravity irrigation systems, who were more interested in raising yields than conserving water (Cabangon, 2002). To make full use of the potential of dry seeding in saving water and increasing water productivity, it is important to enhance the farmer's acceptance of dry seeded rice by improving its yield.

The coefficients of other variables included in the stochastic frontier production model, namely labor, fertilizer and chemicals, were not significant in determining paddy output. The insignificance of their coefficients, specifically labor, emphasizes the importance of mechanization technologies in rice production.

3.2. Technical efficiency scores

Table 5 shows that the average TE is 0.67. This result closely agrees with the results of Karami and Zibai (2001), who calculated a TE of 0.69 for the Mazandaran province, but it is inconsistent with studies that revealed a mean TE of more than 0.85 for the rice producers (Shamsabadi and Moradi, 2001; Tan, 2010; Shehu and Meshelia, 2007).

Furthermore, Table 5 shows that 15% of the respondents operated at an efficiency level greater than 95%. However, 56% of the producers operated at a technical efficiency level below 70%. There was considerable variation with respect to the levels of efficiency among the producers, with a range from 0.15 to 0.99. The TE scores suggest that the respondents, on average, were able to obtain 60–70% of the potential output by using the provided mixture of production inputs. The scores also imply that production can be increased by 33%. In the short run, there is room for improving rice yields for households with efficiency levels close to or higher than the average value; however, households with low efficiency levels can still realize a substantial increase in TE. The mechanization index of rice production in the Khuzestan province ranges from 0.06 to 0.52, which shows a high variation in the application of farm machinery in rice production. A mean index of 0.20 was obtained, which higher than India's index. Sing (2006) have reported that the mechanization index for the paddy crop, which occupies the largest area under cultivation, is 0.08, whereas the mechanization index for wheat is 0.30.

Table 5: Distribution of technical efficiency scores

TE scores	Percentage
0.1– 0.2	1.02
0.2 – 0.3	1.36
0.3 – 0.4	8.81
0.4 – 0.5	13.90
0.5 – 0.6	15.93
0.6 – 0.7	14.91
0.7 – 0.8	13.56
0.8 – 0.9	11.19

0.9 – 0.95	4.42
>0.95	14.9
Mean	0.67
Standard deviation	0.21
Minimum	0.15
Maximum	0.99

The correlation between the mechanization index and technical efficiency demonstrated a positive and significant coefficient of 0.43 ($p < 0.01$). Higher productivity, which requires greater power and mechanization, is one of the most important technologies that can increase production when resources are limited. Deng et al. (2005) have stated that farm machinery contributed to 22–32% of Chinese agriculture. When the TE is close to 1 by means of new mechanization methods, the rice production can be increased.

4. Conclusion

The present study examined the impact of mechanization on the production performance of rice farmers in the Khuzestan province, which is located in the southwest part of Iran. Due to the importance of mechanization technologies in cultivation stages, various cultivation methods were considered in stochastic frontier production. The puddling method, in comparison with other tillage methods, and the mountainous region had a significant positive impact on production. The coefficient of machinery in the harvest stage was significant; however, two-stage harvesting, as compared with multi-stage harvesting, resulted in a negative effect on output, and the output of multi-stage harvesting was not different from the direct method. Because of unsuitable weed management, the dry seeding method, which is a new method that has been applied in recent years, was recognized an ineffective method in the Khuzestan province. There were great variations in the levels of efficiency; the efficiency ranged from 0.15 to 0.99 with a mean of 0.67, which implies that, in the short run, there is extensive room for improving rice yields. The mechanization index is a professional index that can be used at the mechanization level based on machinery operational costs. This index, which ranges from 0.06 to 0.52, showed too much variation in the application of farm machinery in rice production. The correlation between the mechanization index and technical efficiency demonstrated the strong impact of mechanization on the technical efficiency of rice producers caused by the use of appropriate methods. In summary, mechanization should not be considered solely as an increase of mechanical power. Rather, the selection of systems is a key choice because a certain system will change the inputs that should be used.

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